HISTORICAL PERSPECTIVE AND BASIC CONCEPTS OF DEVELOPMENTAL BIOLOGY

Dr. R. Prasad
Department of Zoology,
Eastern Karbi Anglong College,
Sarihajan

10.1 INTRODUCTION

In the last two blocks of this course you learnt about the diversity in the anatomy of vertebrates. In the following units of this course we will learn about the progressive period of animal development during which the various organ systems develop in vertebrates. In order to achieve this you will study how various processes occur in the development of mature male and female gametes, called sperms and ova (or eggs) respectively in vertebrates. You will also become familiar with the events that occur prior to and during the period of fertilization (union of sperms and ova) which results in the formation of a single celled zygote that consists of genetic material from both parents. This zygote through various stages and cell processes develops into a multicellular organism that is capable of functioning, growing, reproducing and completing its life cycle. The process of development of the zygote from a single celled entity to a multicellular embryo is long. In humans as you may be aware the duration of development of the zygote into a fully developed foetus, ready to be born is approximately nine months.

10.2 DEVELOPMENT STAGES COMMON TO ALL ANIMALS

The blueprint of development of an organism from a fertilized egg to an adult is encoded in (i) genes present in the zygote and (ii) some special clues in the form of cytoplasmic determinants present in the cytoplasm of the zygote. During the course of development, the developing cells of the zygote

differentiate into many cell types that communicate and coordinate the various developmental activities and then subsequently get organized to form an integrated functional organism.

A development principle common to all higher organisms is that, the fertilized egg or zygote will develop progressively during several stages that last for different periods in order to form an integrated functional organism.

The stages of development that occur between fertilization and the birth of an organism (Fig.10.1) are collectively known as embryogenesis. It is during embryogenesis that the genotype (genes of the developing organism) of the organism determines the morphological appearance (phenotype) of the organism. Each animal whether it is a fruit fly or earthworm or frog, or bird or a mammal undergoes the same basic stages of development which include:

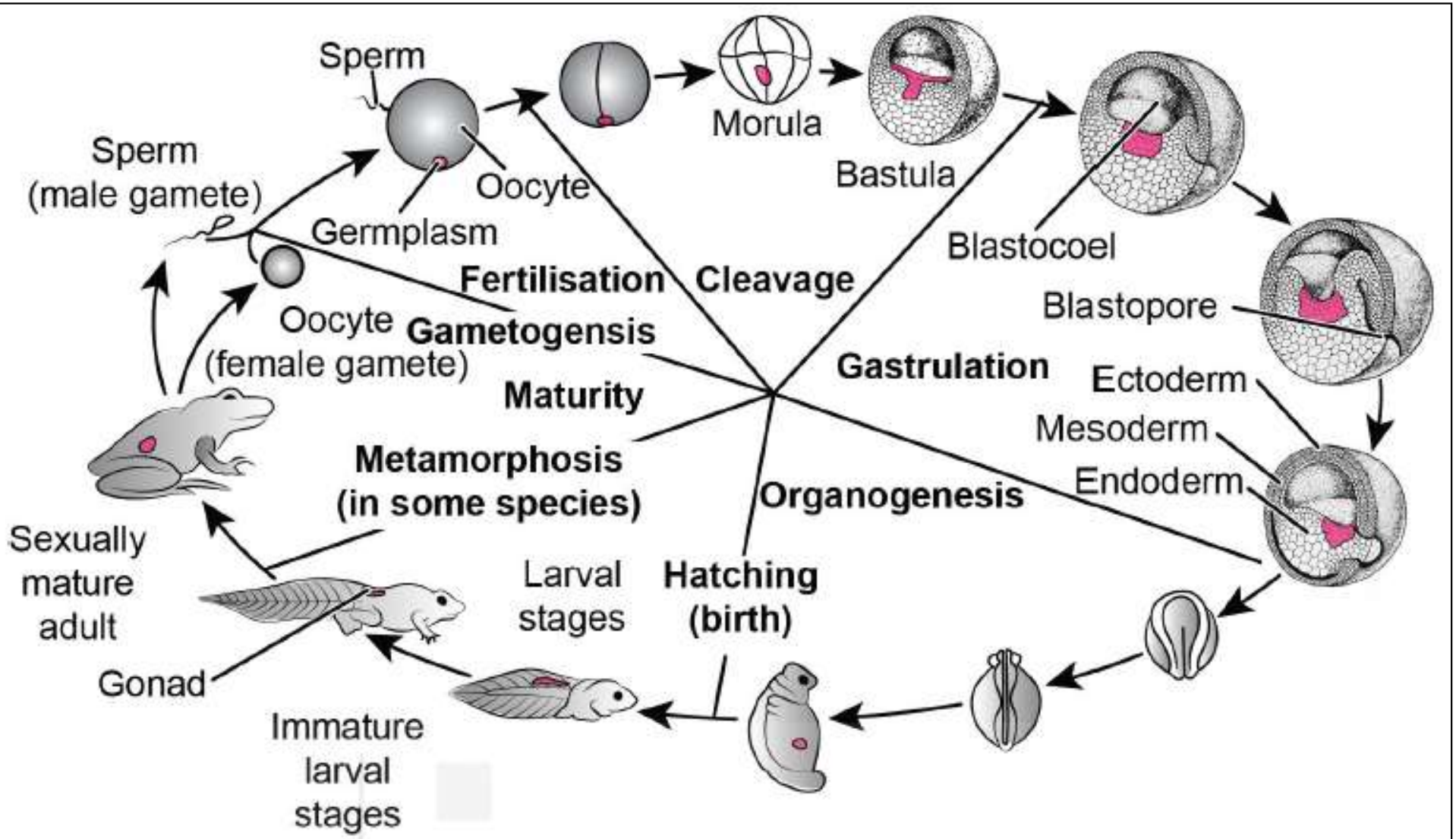

Fig 10.1: Life cycle of a frog, showing, the various stages from fertilisation and embryogenesis. In the frog the egg hatches as a larva (tadpole) and completes the rest of development through steps of metamorphosis; finally emerging as the adult frog capable of starting another generation.

i) **Fertilisation** – involves the fusion of mature male and female sex cells or gametes. Each gamete has only half the complements (set) of the chromosomes of the adult organism and union of the male and the female gamete to form the zygote restores the full genetic complement. The full genetic complement of the zygote instructs the zygote to develop in a similar manner to the parents and to produce an organism similar to the parents.

ii) **Cleavage or rapid cell division** – is the stage in which the zygote is divided into numerous small cells known as blastomeres. During cleavage cells do not grow between each division and so with successive cleavage cells the **blastomeres become** smaller. These smaller blastomeres develop into early stages of development called **morula and blastula** stages.

iii) **Gastrulation** – is the stage during which the cell division slows down and cells of the blastula undergo dramatic movement and rearrangement causing **cellular diversity** and formation of the three germ layers namely, ectoderm, mesoderm and endoderm. These three layer interact to form the organs of the body.

iv) **Morphogenesis** – is the process **of cellular differentiation in the embryo**. Morphogenesis gives the embryo its shape.

v) **Organogenesis** – is the process in which organ formation is completed so that the embryo becomes functional. A fully developed individual organism can then be distinctly seen as a member of a particular species at this stage. The embryo then, takes birth as a formed individual that lives on, till its death.

In many species a group of cells are set aside and do not participate in the formation of the embryo. These are known as germ cells and are used to produce the next generation. All other cells of the body are known as somatic cells. The germ cells migrate in the embryo to form the gonads and give rise to gametes in the adult organism. However, the process of development does not stop at birth, it is seen as metamorphosis and regeneration in some animal groups and finally as aging or senescence.

10.3 HISTORICAL BACKGROUND OF DEVELOPMENTAL BIOLOGY

History of animal development is believed to have begun in the 4th century BC with simple observations of egg and embryos that could be seen with the naked eye. Aristotle was the first to record variations in life cycles of animals. He noted that some animals are born from eggs (**oviparity**) as seen in most invertebrates and some vertebrate groups like frogs and birds. He also noted that in some animals, embryos were born directly as young ones (**viviparity**) as seen in all mammals except for monotremes. He furthermore, observed that some animals were born from eggs that hatched within the body (**ovoviviparity**) as seen in some snakes and sharks. Aristotle also observed two types of division patterns in the fertilized egg as the embryos undergo cleavage namely: 1) **holoblastic** division where the entire embryo divides to form smaller cells as seen in frog and mammals, and 2) **meroblastic** division pattern of division where only a part of the fertilized egg divides and the rest provides nutrition for the embryo as seen in the chick.

Aristotle, on the basis of his studies on the development of chick embryo, for the first time advanced the **theory of epigenesis** (meaning: 'determination/ upon formation') for the development of organisms. According to the epigenesis theory, new structures develop progressively in the embryo during development. Thus, according to this theory there was no preformed tissue or organ in the embryo at the beginning of development.

However, the theory of epigenesis was not the only theory of animal development. The more popular theory that emerged later was that of preformation of embryo in development.

According to **the preformation theory,** all the parts in the embryo were preformed and they just got bigger with time. Preformationists believed that a preformed miniature, that is a fully formed infant, called the **homunculus** (Fig.10.2), existed within the germ cell of one of its parents, prior to fertilization and this would grow and enlarge into its full form during gestation until ready to be born. The Preformationists were thus either spermists or ovists. Spermists believed that the **homunculus** existed in the sperms while the ovists believed they were contained in the eggs.

Fig.10.2: Pre formation theory depicted by homunculus.

Very little progress was made in the field of embryology and it was only in 1651 that William Harvey concluded that all animals arise out of eggs. He was the first to see the blastoderm of the chick which is the clear, yolk free germinal disc, also called the blastodisc and is in the form of a single layer of embryonic epithelial tissue and gives rise to the chick embryo. William Harvey saw the red dots of pooled blood that arose before the formation of the heart or vessels.

The two theories preformation and epigenesis were debated till the 17th and early 18th century. Kasper Freidrich Wolff, extended Aristotle's observations and supported epigenesis which disputed the idea of preformation. He observed the developing embryo of chick and demonstrated that the embryo takes its form from tissues that are not seen in the adult organism. The heart, intestine and blood cells all could be seen forming as new in each embryo and there were no preformed miniature organs. The final end to the preformation theory came only in the 1820s when the cell theory came in existence.

The cell theory in combination with newer staining techniques and improved microscopy contributed to the development of the discipline of descriptive embryology. Christian Pander (1794-1865) first recognized the existence of three germ layers (ectoderm, mesoderm, and endoderm) in the chick embryo. He also wrote about the interdependence of these layers in forming the embryo. A few years later Martin Rathke (1793-1860), another embryologist discovered layers of cells similar to what Pander had described in the crayfish and put forth the idea that three germ layers were not only found in vertebrates but also in invertebrates.

While studying embryos of vertebrates, embryologists discovered that there were many embryonic similarities between vertebrates belonging to different groups. Karl Ernst Von Baer, in 1828 proposed this to be an evidence of evolution and put forth his four laws of animal development; Von Baer described his laws of embryology in his book *Über Entwickelungsgeschichte der Thiere* [On the Development of Animals, published in 1828 and 1837]. In his work, von Baer reviewed existing information on the development of vertebrates. He used the information in this review to extrapolate his laws. These laws, translated by Thomas Henry Huxley in *Scientific Memoirs* are as follows:

1) The more general characters of a large group appear earlier in the embryo than the more special characters

2) From the most general forms the less general are developed, and so on, until finally the most special arise

3) Every embryo of an animal form, instead of passing through the other form, rather becomes separated from them

4) Fundamentally therefore the embryo of the higher form never resembles any other form but only its embryo

The explanations of the four laws given by Von Baer are as follows:

i) The first law meant that in embryos of an animal group, the general characters develop first before the specialized characters develop. **His first law thus contradicted the preformationist theories.**

ii) The explanation of his second law is that, embryos develop from a uniform and noncomplex structure into an increasingly complicated and diverse organism. For example, a defining and general feature of vertebrates is the vertebral column. This structure thus, appears early in the embryonic development of vertebrates. Other features those which are more specific to a group within the vertebrates, such as hair on mammals or scales on reptiles however, form later during development. **Von Baer thus, concluded from the first two laws that development occurs through epigenesis, and the complex form of an animal arises gradually from unformed material during development and not from preformed structures.**

iii) Von Baer's third law referred to the fact that animals from different species start to develop in a similar manner but become more dissimilar from one another as ontogeny (the origination and development of an organism, usually from the time of fertilization of the egg to the organism's mature form—although the term can be used to refer to the study of the entirety of an organism's lifespan) proceeds. As an example, von Baer discussed the embryos of humans, fish, and chicks, all of which appear similar to each other in the early stages of their development. As they grow, however, they look increasingly different from one another. The embryo of one species never resembles the adult of another species. **Von Baer's third law thus, theorized that animal embryos diverge from one or a few shared embryonic forms.**

iv) The fourth law meant that the stages of development in more complex animals never represent the adult stages of less complex animals.

In the second half of the 19th century another professor in Germany Ernst Haeckel extended the theory of recapitulation which was stated as the 'biogenetic law'. He proposed that **"Ontogeny repeats Phylogeny"**. This means that the stages of ontogeny (development) of the organism replay that organism's evolutionary history. The biogenetic law has been widely disputed, though Von Baer's laws are generally believed to have been responsible for the progress of developmental biology in the twentieth century.

The tools used by early embryologists were simple. Embryological studies involved the use of moulds made of wax or glass strips, direct observation of embryos of various animals, and their manipulation with the help of glass needles which were also used to move and pick embryos. Glass pipettes were also used to pull the embryo by narrow tubes for transfer. Embryologists of that time faced a difficult task in manipulating the embryos and ensuring their survival without them being infected, before they could be isolated, removed and transplanted. Later on with the development of better tools and microscopes with better resolution the "Era of Experimental Embryology began".

By the1880s, some embryologists began focusing on various experimental methods in order to understand embryogenesis. For this purpose the embryologists used physical manipulation of the embryo rather than just observing and describing them. The German evolutionary biologist, August Friedrich Leopold Weismann (1834-1914) put forward a model of development in which he assumed that the nucleus and cytoplasm of the zygote contained some special factors or determinants. He proposed that during cleavage these determinants would be unevenly distributed in the dividing cells and so could control future development. The fate of each cell according to him was, therefore, predetermined in the egg by these factors. He called this type of development mosaic. His theory was supported by the experiments conducted by the German Zoologist, Wilhelm Roux (1850-1924), in late1800s on frogs. Wilhelm Roux in his experiments destroyed one of the blastomeres of the frog embryo after the first cleavage by using a hot needle. He found that the other blastomere formed half of the embryo (Fig.10.3). He thus, concluded that development was based on mosaic mechanism and the cells have their characteristic fate determined at each cleavage.

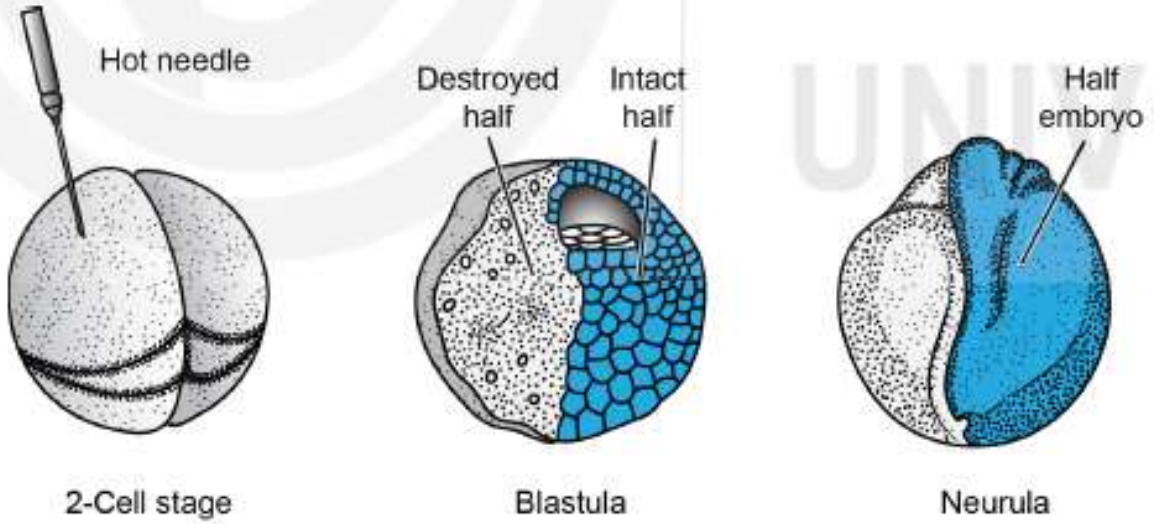

Fig.10.3: Experiment done by Roux that supported Weismann's theory of mosaic development.

Another German biologist Hans Adolf Eduard Driesch (1867-1941) found something quite opposite; he used sea urchin eggs and separated them after the first cleavage. He found that one blastomere died and the other formed a smaller but complete larva (Fig.10.4). He called this type of development **regulative,** referring to the ability of the embryo to restore normal development even though one cell had died. We will learn more about determinants and these two types of development namely mosaic and regulative when we discuss specification in cells.

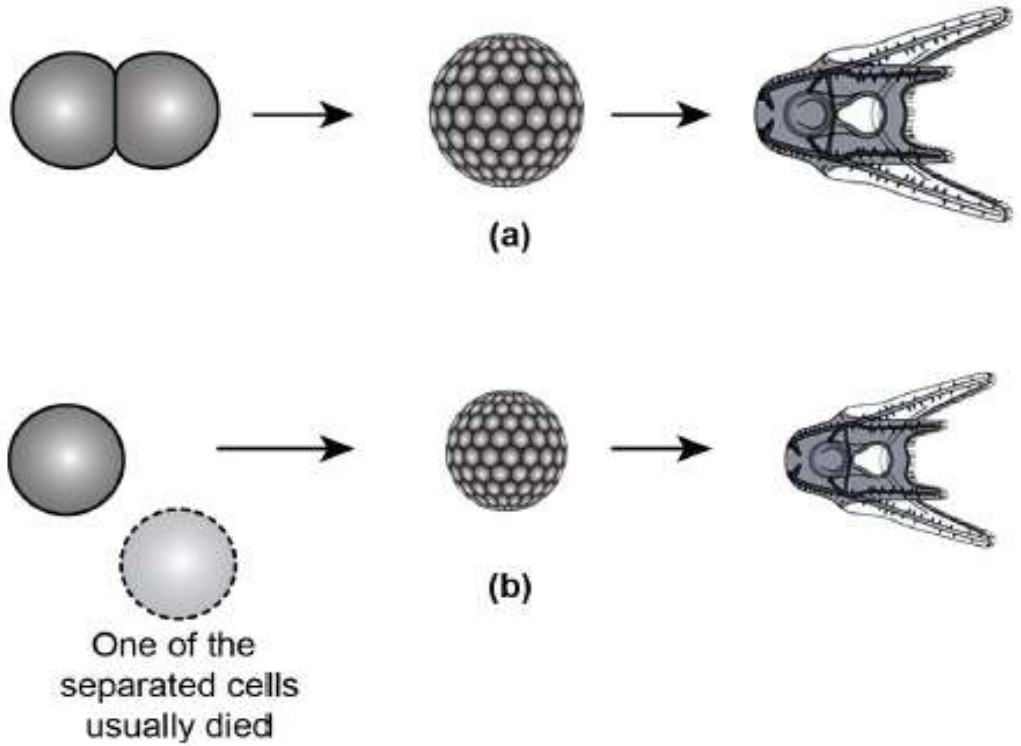

Fig.10.4: Driesch's Experiment with sea urchin blastula that demonstrated regulative development for the first time. a) normal development of sea urchin larva from two cell stage; b) separation of cells at two cell stage resulted in the death of one cell but the other survived to develop into a fully formed smaller larva.

The next major step in experimental development biology came in 1924 when German embryologist, Hans Spemann (1869-1941), and his graduate student Hilde Mangold proposed the concept of '**organizer**' and the principle of embryonic induction during development as seen in the development of amphibian embryos. Their work (Fig.10.5) showed that, in the earliest stages, the fate of the embryonic parts is not determined and if a piece of presumptive skin tissue is excised and transplanted into an area of presumptive nervous tissue, it will form nervous tissue, not skin. It provided the first unambiguous evidence that cell and tissue fates can be determined by signals received from other cells. This experiment is probably the best known in embryology.

The groundbreaking and technically demanding experiment was performed in newt embryos at the gastrulation stage, the period during which the three primary germ layers the ectoderm, mesoderm and endoderm become established. The experiment involved transplantation of a structure present on the dorsal side of the blastopore stage of the embryo, called the dorsal lip, to the ventral side of another embryo. By grafting tissue between differently pigmented *Triton* species, the fates of the graft and host tissues could be distinguished. This graft, nowadays referred to as the **Spemann organizer** (also the Spemann–Mangold organizer) had two effects. It induced the formation of neural tissues (neuralization), from the ectoderm that would have generally formed the skin. Furthermore it caused dorsalization of the ventral mesoderm, leading to the formation of somites.

This experiment therefore, demonstrated the existence of an organizer that instructs both neuralization and dorsalization, and showed that cells can adopt their developmental fate according to their position when instructed by other cells. The molecular nature of this signal remained elusive until 65 years later and is still not completely understood. Hans Spemann was awarded the Nobel Prize, in 1935, for his discovery of the effect now known as **embryonic induction**

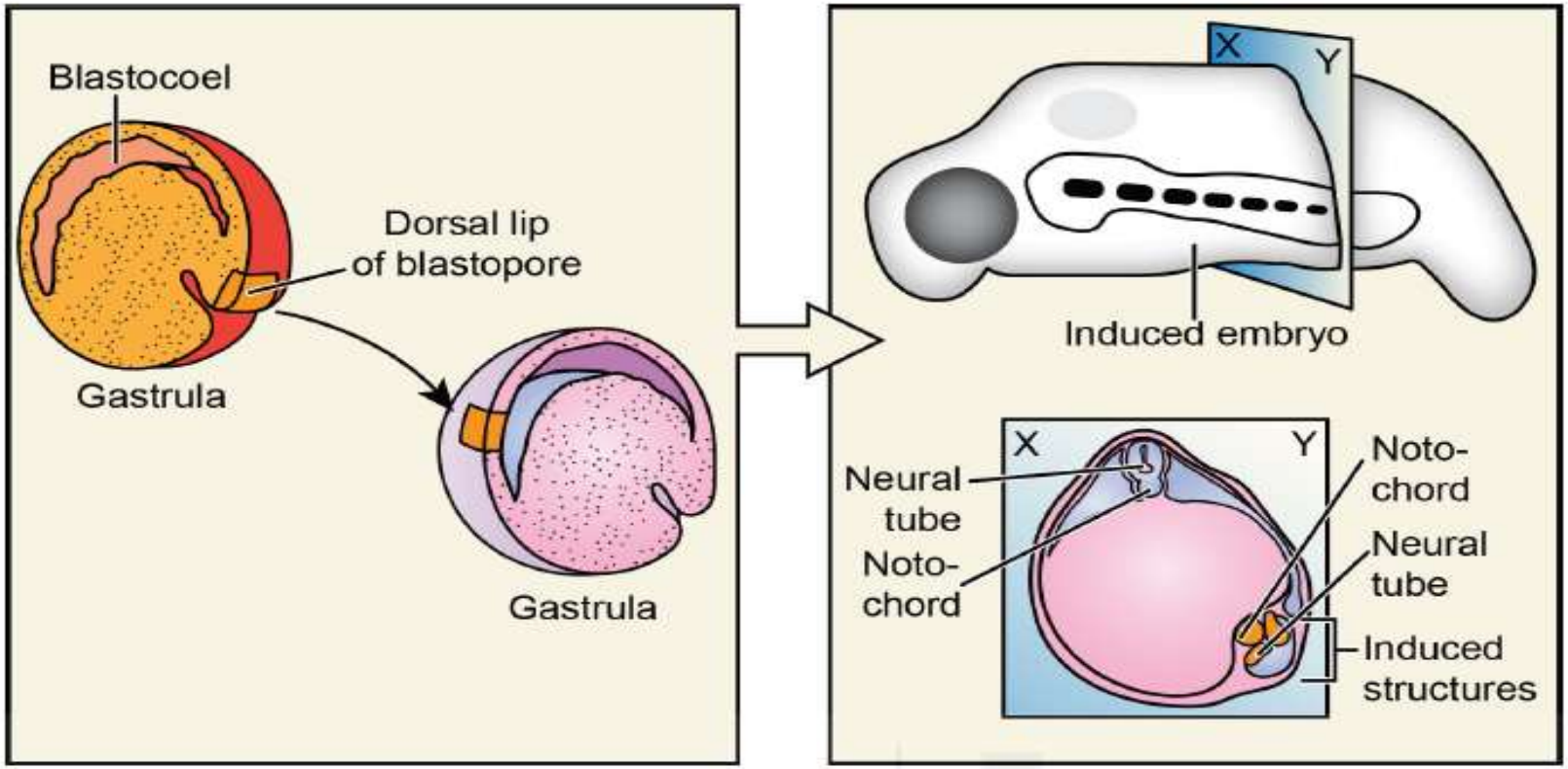

Fig.10.5: Experiment conducted by Spemann and Mangold that demonstrated induction of a new main body axis by the organizer region in early amphibian gastrula. a) dorsal lip of blastopore from unpigmented species grafted on the blastocoels roof of a pigmented species; b) a secondary embryo is induced.

Towards the middle of the 20th century, the scientific discipline of embryology began to emerge as the modern discipline of developmental biology. As is true for other disciplines in biology, knowledge of animal development advanced: (i) as new techniques for experimentation were invented and (ii) with the progress in knowledge of other branches of biology such as cell biology genetics, and especially molecular biology with the discovery of DNA, and the processes of transcription, translation and gene regulation.

With the increase in the knowledge of molecular biology, development biology emerged as a field of study which attempted to correlate genes with the morphological changes that were observed in embryos undergoing development. Which genes were causing which morphological changes and how these genes were controlled to express at certain stages of development became an exciting subject for research for many biologists. It thus became clear that genes which all embryonic cells contained, switched on and switched off as and when required in the developing embryo.

More recently, experiments on gene expression have demonstrated clearly that even in widely different animals, body plans share many basic features and mechanism of development. They are controlled by a common set of regulatory genes which direct cells to become capable of distinct functions. For example, the position for formation of eyes in a vertebrate like the mouse has a close counterpart with a nearly identical function in the fruit fly *Drosophila* which is an invertebrate.